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Comparasion of composition of brake pad hardness and wearness

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ABSTRACT

This study aims to identify the most optimal material composition in achieving the best combination of hardness and wear. The experimental method was conducted using a special test bed designed to test the mechanical properties of various material compositions. The material specimens used were weighed before and after the test to calculate the wear rate by observing the change in specimen mass. The results showed that the 50:50 material composition performed significantly better than the 60:40 composition in terms of hardness and wear properties. These findings suggest that the 50:50 composition may be a superior choice in various applications where a combination of strength and wear resistance is required, such as in the manufacturing industry, materials engineering, or the automotive sector. This research provides valuable insights into material selection that can improve the performance and durability of the final product.

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1. INTRODUCTION

Braking system technology is a part of a vehicle that continues to experience development from time to time (Arifin, 2017; Karim et al., 2023; Sultan et al., 2022). This development occurred in order to balance the increase in engine performance and increased safety so that it can produce shorter braking distances, while the braking performance will be influenced by several factors, including: road profile, friction coefficient between the tire surface and the road, vehicle weight and the profile of the brake linin it self (Austin & Morrey, 2000; Mannering & Washburn, 2020; Niemz, 2014).

At this time there are two different types of brake linings on the market, namely asbestos brake linings and non-asbestos brake linings (Kennedy et al., 2019; Santoso, 2013). The use of asbestos brake linings is used because brake linings made from asbestos are cheap, but asbestos brake linings work at temperatures of 200oC and produce toxic dust which can be dangerous for health because it can cause fibrosis (thickening and scratches in the lungs) and when the asbestos brake lining is exposed to water, its braking ability is reduced. This is different from non-asbestos brake linings which do not produce toxic dust so they are friendlier to the environment and if non-asbestos brake linings are exposed to water they can still work optimally (Irawan et al., 2022; Sathyamoorthy et al., 2022; Yashwhanth et al., 2021).

At present, much has been done to obtain environmentally friendly, renewable and economical brake linings, but the results currently achieved have not been able to maintain the mechanical properties, especially in terms of wear resistance, temperature, vibration and sound absorption and the costs are still relatively expensive (Leyland & Matthews, 2004; Muratoglu et al., 2001; Wang et al., 2021).

Corn cobs (Myristca fragrans) are a commodity crop in Indonesia, therefore in the 1800s Europeans came to Indonesia to take corn cobs to be used as a spice. But at that time corn cobs were not only used as spices but could be used in other fields such as the skin on corn cobs which was used as an anti-biotic ingredient. The fruit from corn cobs could be used as oil which could be used as a base for perfume and bio diesel (Bharath et al., 2020).

The problem that arises in the corncob production process is waste. Corn plant waste that is still not widely used is corn cobs. Currently, in rural areas many corn cobs are simply thrown away and some are used as fuel and briquettes. So in this study we will try to use corn cobs as a raw material for Non-asbestos brake linings. Research on composites made from organic composite materials for the manufacture of non-asbestos brake linings has been widely developed. This research is considered necessary because as a solution to treat waste as a useful product and increase the value of engineering corncob shell materials in the automotive technology industry over time, this is something that must be faced. The materials needed for this technology must also continue to be innovated from materials that are difficult to obtain in nature to easy to obtain, such as composite materials. So that the creation of a technology that is cheap and environmentally friendly. In the development of composite technology, this progress has been very rapid due to its special renewable properties and also a high ratio of strength to weight, stiffness, resistance to corrosion, etc., thereby reducing the consumption of chemicals and environmental disturbances (Rajak et al., 2019).

Of the components on a motorbike that must always be checked and replaced regularly are the brake linings, this is because the brake system has a vital function for driving comfort and safety. Several things to pay attention to regarding the lining include the grip strength of the brake lining and the thickness of the brake lining when pressing the brake pedal. The gripping strength of the brake lining is very dependent on the material of the brake lining. The materials for brake pads sold on the market are asbestos, steel fiber, cellulose, rock wool, gravite and kevlar (Ahmed et al., 2022). Of the brake lining materials in circulation, there are those whose use has been banned, such as asbestos because it has very dangerous effects on health, namely it can cause cancer [6]. Meanwhile, other materials will become increasingly rare in nature, so it is necessary to look for other alternatives as friction materials for brake pads. Apart from that, the material from the factory usually reduces the friction force against the disc disc over time, even though the thickness of the brake lining is still within tolerance according to the manufacturer's instructions so that the user is forced to replace it. To overcome this problem, various types of brake lining materials have been developed.

Brakes have a working principle by changing kinetic energy into heat energy, so a material that is good at absorbing heat is needed, namely aluminum. Aluminum is a metal that is abundantly found on earth and when used it is not harmful to health, so it is very suitable to be combined with corn cob shells. The availability of coconut fiber and pineapple leaves is quite abundant in North Suatra. Pineapple leaf fiber and coconut fiber which are processed in various ways are usually only used for clothing, rope and crafts as a substitute for thread. In this research, we will try to use pineapple leaf fiber and coconut fiber as a substitute for fiber which is usually used in the process of making brake linings, so that it is hoped that it can increase the flexural strength of the brake lining.

Composite materials are defined as a mixture of two or more materials that produces a new material whose properties or characteristics are still dominated by the properties of the constituent materials (LLorca et al., 2011).

The matrix is the phase in a composite that has the largest (dominant) part or volume fraction. Matrix, generally more ductile but has lower strength and stiffness (Evans et al., 2003; Llorca et al., 1991).

The matrix has the following function.

1. Transfer stress to the fiber.
2. Forms a coherent bond, matrix/fiber surface.
3. Protects fiber.
4. Separating fibers.
5. Untying.

6. Keep stable after manufacturing process.

The purpose of making composites is to improve certain mechanical properties or specific properties, simplify difficult designs in manufacturing, flexibility in shape or design which can save production costs, and make the material lighter. Composites produced by an agency or factory can usually predict the mechanical properties of the composite material based on the matrix and reinforcing materials.

Manufacturing techniques for polymer composite materials generally do not involve the use of high temperatures and pressures. This is because this material easily becomes soft or melts. The process of mixing the amplifier into the matrix is carried out when the matrix is in a liquid state.

Several methods of making polymer composite materials that are commonly used are three, namely:

1. Direct pouring method (hand lay-up).
2. ompression / pressure method
3. Method of applying pressure

The compaction process is the process of compacting the powder into a sample with a certain shape according to the mold. The powder will bind to each other and the air voids between the particles will be pushed out (Capes, 2013) . The greater the compaction pressure, the less air (porosity) between the particles, but it is impossible to achieve zero porosity. The result of compaction is usually called a green body.

There are two types of compaction methods, namely:

1. Cold compressing, namely compression with room temperature. This method is used when the material used is easily oxidized.
2. Hot compressing, namely pressing with temperatures above room temperature. This method is used if the material used is not easily oxidized.

The friction material formula for brake lining materials has a big impact on braking quality, vibrations and sounds that occur when braking. By varying a particular material, engineers can modify the formula for a more suitable brake lining application for a variety of vehicles. The key to understanding what type of formula to make the best one for a particular application is simplified by looking at the current original equipment (OE) recommendations, there are three universally accepted friction material formulations for brake linings. The strength of the brake particle composite material is greatly influenced by the size of the particles, the material matrix and the manufacturing process. The strength of the composite particles is maximized at the size of 0.01 to 0.1 mm and the strength of surface bonding, pressing and sintering (Khomenko et al., 2009).

Coconut (Cocos nucifera) is one of the most well-known members of the palm plant and is widely distributed in the tropics. Coconut tree is a type of plant that has one house with plant stems growing straight up and not branching. Coconut trees can reach more than 10-14 meters in height, their leaves have midribs that can reach more than 3-4 meters in length with fins that support each strand.

Aluminum is a chemical element with the symbol A1 and atomic number 13. Aluminum is the most abundant metal. Aluminum is not a heavy metal, but it is an element that accounts for about 8% of the earth's surface and is the third most abundant. Aluminum is found in the use of food additives, antacids, buffered, aspirin, astringents, nasal sprays, antiperspirants, drinking water, car exhaust, tobacco smoke, use of aluminum foil, cooking utensils, cans, ceramics and fireworks (Wikipedi.org).

The advantages of aluminum metal are that it weighs one third of the weight of steel (p: 2.7 g/cm), has good heat and electrical conductivity, high strength to weight ratio, is resistant to corrosion, has good formability properties and is easy to print (Choi & Park, 1998; Miao & Laughlin, 2000).

One of the preferred properties of polyurethane is its ability to be converted into foam, when water reacts with isocyanate it will produce carbon dioxide gas which fills and expands the cells created in the mixing process. In this process a three-step process occurs, namely water reacts with the isocyanate group to form carbanic acid, carbanic acid is unstable and its decomposition forms carbon dioxide and an amine. Amine reacts with isocyanate to produce artificial urethane (Khatoon et al., 2021) .

There are two sources for making polyorethanes, namely the reaction of bischloroformat with diamines and the reaction of isocyanates with dihydroxy compounds. Linear polyorethanes are usually prepared in solution because these polymers tend to dissociate to alcohols and isocyanates or decompose to amines and carbon dioxide at the high temperatures required for melt polymerization. Fused polymerization applies to polyurethanes prepared with aromatic isocyanates (Sienkiewicz & Czub, 2017).

Isocyanate is an adhesive that has a higher strength than other adhesives (Wikipedia 2012). Isocyanes react not only with aquarous but also with wood to produce very strong chemical bonds (chemical bonding). Isocyanates also have very reactive chemical groups, namely R-N=C=O. The uniqueness of isocyanate adhesives is that they can be used for a wide variety of temperatures, are water resistant, heat resistant, fast dry, PH neutral and impermeable to solvents (organic solvents). Isocyanates have the advantage of long thickening (Siqueira et al., 2010).

Friction is the main factor of braking. Therefore components made for brake pads must have material properties that not only produce a large amount of friction, but also must be resistant to friction and not produce heat that can cause the material to melt or change shape. Materials that are resistant to friction are usually a combination of several materials that are put together by carrying out certain treatments. A number of these materials include: copper, brass, timsh, grsfit, carbon, kevlar, resin/resin, fiber and other addictive/additional materials (Graedel et al., 2015) .

2. RESEARCH METHOD

The types of brake pads according to the international classification are (Jadhav & Sawant, 2019):

1) OME (Original Equipment Manufactured)

OME is a type of brake lining that is already installed when buying a new motorbike, where for Honda, Suzuki and Kawasaki manufacturers it is issued by the brake manufacturer Nissin, while for Yamaha it is issued by Akebono.

2) OSE (Original Equipment Spare Parts)

OES is a type of brake pad that is used as a replacement for OEM brake pads where the brake pads are made by an OEM manufacturer so they have the same formula code, the same process, the same quality and the same materials as OEM brake pads.

3) AM (After Market)

This type is the brake pads on the market, with varying qualities. Some have lower quality than OEM and some have higher quality than OEM.

4) Genuine

Basically, this type of brake lining is included in the After Market type category. The term Genuine is only to distinguish between genuine and fake products.

Mechanical properties describe the ability of a material (such as a component made of that material) to accept a force/energy load without causing damage to the material/component. Often when a material has good mechanical properties but is not good at other properties, steps are taken to overcome these deficiencies in the necessary ways. In order to obtain a reference standard for brake lining technical specifications, the value of hardness, wear, bending and other mechanical properties must be close to the value of the safety standard.

The technical requirements for composite brake pads (Xiao et al., 2018) are:

a. For hardness values according to safety standards 68 –105 (RockwellR)
b. Heat resistance 360°C, for continuous use up to 250°C
c. Brake lining wear value is (5 x 10 – 5 x 10 mm/kg)
d. Friction coefficient 0.14 – 0.27
e. The density of the brake pads is 1.5 -2.4 gr/cm^3
f. Thermal conductivity 0.12 – 0.8 W.m.°K
g. The specific pressure is 0.17 – 0.98 joules/g.°C
h. Shear strength 1300 – 3500 N/cm^2
i. The fracture strength is 480 – 1500 N/cm^2

Wear and tear occurs when two objects are pressed against each other and rub against each other. Greater wear occurs in softer materials. Factors that influence wear are speed, pressure, surface roughness and material hardness. The greater the relative speed of the objects rubbing against each other, the higher the wear rate. Likewise, the greater the pressure on the contact surface of the object, the faster the material will wear out, and vice versa. Wear is defined as the detachment of atoms from the surface of a material and reduction in size as a result of mechanical action. The level of wear of a material can be tested using laboratory-scale wear testing equipment. The wear test equipment used is as shown in Figure 1. below.

Figure 1. wearness tester

To get the wear value of the specimen, first the specimen must be weighed first. After the test is complete, the specimen is weighed again, so that the change in mass of the specimen is obtained, which is then used to calculate the wear rate. The wear calculation is expressed by the amount of loss of specimen reduction per unit area of contact and wear time(Wu & Cheng, 1991) . Wear rate is expressed by (Kubo & Kato, 1999) :

$$W=(W0-W1)/(A\ .t) \quad \text{…………………. (1)}$$

Where , W = Wear rate (gram/mm^2 sec)
W0 = initial weight of specimen before wear (grams)
W1 = Final weight of specimen after wear (grams)
A = Area of contact area with wear (mm^2)
t = wear time / length of wear (seconds)

The friction coefficient is a quantity that shows the level of surface roughness of an object when two objects are rubbing together. Mathematically, the friction coefficient is formulated as a number resulting from the comparison between the magnitude of the friction force and the magnitude of the normal force of an object. So the value of the friction coefficient is determined by two factors, namely the level of roughness of the two contact areas and the normal force acting on the object. The magnitude of the normal force that acts on an object is proportional to the weight of the object, because the weight of the object only acts on the surface. So that mathematically the magnitude of the normal force is the same as the gravity force,

$$N = w = m.g \quad \text{……………………….. (2)}$$

The friction coefficient (μ) can be defined as the ratio between the friction force (F) and the normal force (N), which can be formulated as follows:

$$\mu=F/N \quad \text{……………………….. (3)}$$

The purpose of this friction coefficient test is to find the value of the friction coefficient of the brake canvas and the drum

The method used in testing the coefficient of friction is based on ASTM C1028. The ASTM C1028 standard regulates methods for testing the coefficient of friction.

Figure 2. Friction coefficient test equipment

3. RESULTS AND DISCUSSIONS

a. Hardness Testing

Hardness testing is carried out on the surface of the brake lining at five test locations and then averaged to obtain a hardness value. The results of the hardness test using the B scale Brinell hardness test from the test results for side A brake lining hardness with a composition of 40:60% and a composition of 50:50% can be seen in Table 3 below;

Table 3. Brake lining hardness test composition 40:60% and 50:50% side A

Test	Hardness Value (HRB) Sisi A	
	60:40%	50:50%
1	56	77
2	61.5	73
3	63	76
4	56	73
5	64	71
Average	61.1	74

To make it easier to see the results of the brake lining hardness test on side A, it can be seen as in Figure 3 below.

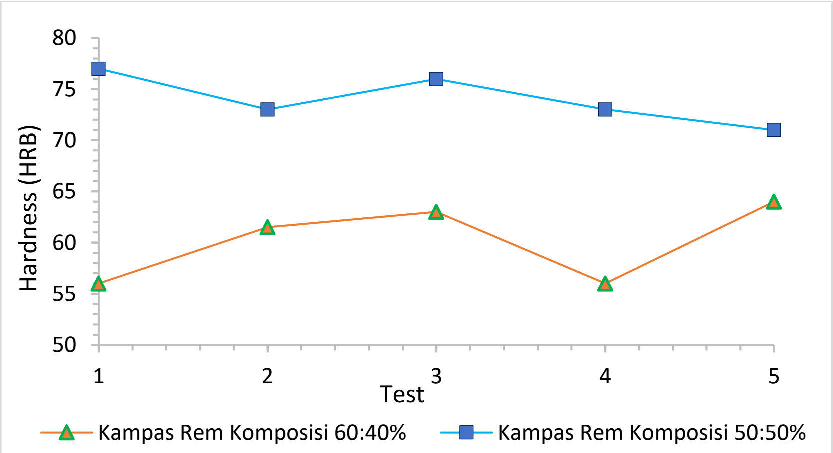

Figure 3. Brake Pad Hardness Value Composition 60:40 Vs 50:50 Side A

From Figure 3, it can be seen that in general the composition of brake linings with 50% fiber and 50% binder has a higher hardness value compared to brake linings made with a composition of 60% fiber and 40% binder. In the 50% fiber brake lining composition, the highest test value occurred in the 5th test with a hardness value of 71 and the highest hardness value was in the 1st test with a hardness value of 77 and an average hardness value of 74, while for brake linings with the composition 60% fiber and 40% binder the lowest hardness value obtained in the 1st and 4th tests was 56 and the highest hardness value in the 5th test was 64.

The results of hardness testing using the Brinell scale hardness test and the results of hardness testing for side B brake linings with a composition of 40:60% and a composition of 50:50% can be seen in table 4 below;

Table 4. Brake lining hardness test composition 40:60% and 50:50% side B

Test	Hardness Value (HRB) Side B	
	60:40%	50:50%
1	60	71
2	62	76.5
3	54	76
4	64	73
5	58	74
Avarage	59.6	74.1

To make it easier to see the results of the brake lining hardness test on side A, it can be seen as in Figure 4 below.

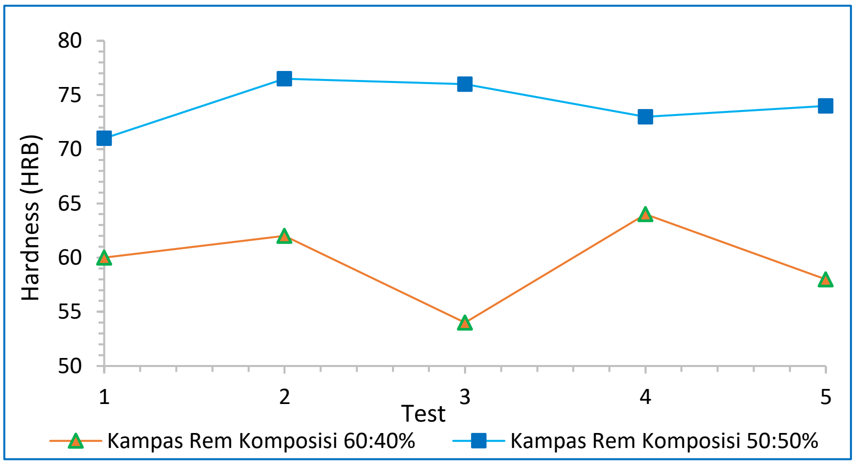

Figure 4. Brake Pad Hardness Value Composition 60:40 Vs 50:50 Side B

a. Wearness Testing

The results of the brake lining wear test on side A with a composition of 50:50% and 60:40% can be seen in table 5 below.

Table 5. Wearness Value of Brake pad side A

Test	Composition 50:50%	Composition 60:40%
1	2.54959×10^{-6}	3.72291×10^{-6}
2	1.03991×10^{-6}	1.90650×10^{-6}
3	1.60319×10^{-6}	2.46978×10^{-6}

To make it easier to analyze the results of the brake lining wear test on side A, it can be seen as shown in Figure 5 below.

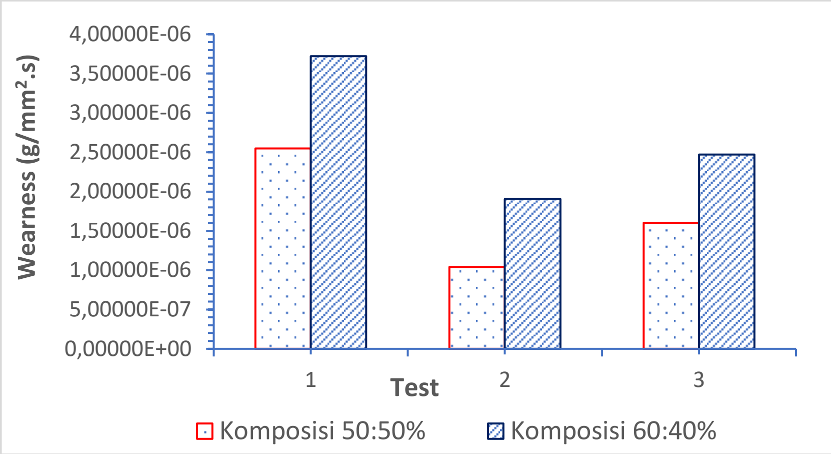

Figure 5. Composite Brake Pad Wear Test with composition 60:40 Vs 50:50% Side "A"

The results of the brake lining wear test on side B with a composition of 50:50% and 60:40% can be seen in table 6 below.

Table 6. Side B brake lining wearness value

Test	Composition 50:50%	Composition 60:40%
1	2.93613 $\times10^{-6}$	4.01937 $\times10^{-6}$
2	1.86317 $\times10^{-6}$	2.07981 $\times10^{-6}$
3	1.38654 $\times10^{-6}$	1.68985 $\times10^{-6}$

To make it easier to analyze the results of the brake lining wear test on side B, it can be seen as in Figure 6 below.

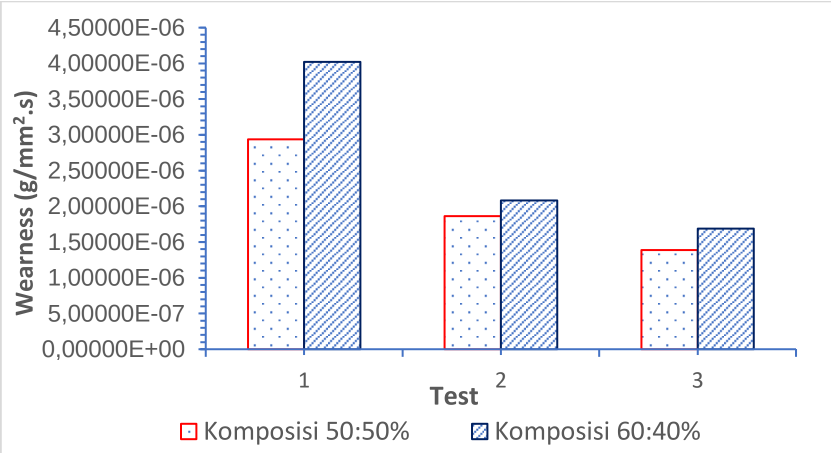

Figure 6. Composite Brake Pad Wear Test with composition 60:40 Vs 50:50% Side "B"

4. CONCLUSION

The main objective was to find a material composition that provides an optimal balance between hardness and wear through testing with a special test bed. The experimental results show that a material composition with a ratio of 50:50 performs better than a 60:40 composition in terms of hardness and wear. These results provide valuable guidance in material selection for applications that require an optimal combination of strength and wear resistance, such as in the manufacturing, materials engineering and automotive industries. These findings can aid in the development of products with superior mechanical properties, improved durability, and reduced maintenance costs in the long run. Research into the development of material compositions to achieve a balance between hardness and wear will continue to grow in the future. This research has the potential to lead to significant innovations in various industries, such as manufacturing, automotive and aerospace, with a focus on material composition optimization, sustainable material development, innovations in testing methods and the integration of advanced technologies such as artificial intelligence. Interdisciplinary collaboration will also be key in deepening the understanding of material properties, leading to the development of more efficient and sustainable solutions. As such, research in this field will remain relevant and important in advancing technology and industry in the future.

REFERENCES

Ahmed, K. A., Mohideen, S. H. R., Balaji, M. A. S., & Sethupathy, P. B. (2022). Synergic effect of metallic fillers as heat dissipaters in the tribological performance of a nonasbestos disk brake pad. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, *236*(2), 292–301.

Arifin, H. A. (2017). Perhitungan Ulang Sistem Pengereman Mobil Nogogeni 3 Evo Untuk Shell Eco Marathon Asia 2017. *Laporan Penelitian Tugas Akhir, Institut Teknologi Sepuluh Nopember, Surabaya*.

Austin, L., & Morrey, D. (2000). Recent advances in antilock braking systems and traction control systems. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *214*(6), 625–638.

Bharath, G., Hai, A., Rambabu, K., Banat, F., Jayaraman, R., Taher, H., Bastidas-Oyanedel, J.-R., Ashraf, M. T., & Schmidt, J. E. (2020). Systematic production and characterization of pyrolysis-oil from date tree wastes for bio-fuel applications. *Biomass and Bioenergy*, *135*, 105523.

Capes, C. E. (2013). *Particle size enlargement*. Elsevier.

Choi, J. C., & Park, H. J. (1998). Microstructural characteristics of aluminum 2024 by cold working in the SIMA process. *Journal of Materials Processing Technology*, *82*(1–3), 107–116.

Evans, A., San Marchi, C., Mortensen, A., Evans, A., San Marchi, C., & Mortensen, A. (2003). *Metal matrix composites*. Springer.

Graedel, T. E., Harper, E. M., Nassar, N. T., & Reck, B. K. (2015). On the materials basis of modern society. *Proceedings of the National Academy of Sciences*, *112*(20), 6295–6300.

Irawan, A. P., Fitriyana, D. F., Tezara, C., Siregar, J. P., Laksmidewi, D., Baskara, G. D., Abdullah, M. Z., Junid, R., Hadi, A. E., & Hamdan, M. H. M. (2022). Overview of the important factors influencing the performance of eco-friendly brake pads. *Polymers*, *14*(6), 1180.

Jadhav, S. P., & Sawant, S. H. (2019). A review paper: Development of novel friction material for vehicle brake pad application to minimize environmental and health issues. *Materials Today: Proceedings*, *19*, 209–212.

Karim, H. A., Lis Lesmini, S. H., Sunarta, D. A., SH, M. E., Suparman, A., SI, S., Kom, M., Yunus, A. I., Khasanah, S. P., & Kom, M. (2023). *Manajemen transportasi*. Cendikia Mulia Mandiri.

Kennedy, R., Surojo, E., & Raharjo, W. W. (2019). Studi Karakteristik Kampas Rem Kendaraan Penumpang Type Oes (Original Equipment Sparepart) Dan Am (After Market) Pada Dry Dan Wet Sliding. *Mekanika*, *18*(1).

Khatoon, H., Iqbal, S., Irfan, M., Darda, A., & Rawat, N. K. (2021). A review on the production, properties and applications of non-isocyanate polyurethane: A greener perspective. *Progress in Organic Coatings*, *154*, 106124.

Khomenko, E. V, Baglyuk, G. A., & Minakova, R. V. (2009). Effect of deformation processing on the properties of Cu–50% Cr composite. *Powder Metallurgy and Metal Ceramics*, *48*, 211–215.

Kubo, S., & Kato, K. (1999). Effect of arc discharge on the wear rate and wear mode transition of a copper-impregnated metallized carbon contact strip sliding against a copper disk. *Tribology International*, *32*(7), 367–378.

Leyland, A., & Matthews, A. (2004). Design criteria for wear-resistant nanostructured and glassy-metal coatings. *Surface and Coatings Technology*, *177*, 317–324.

LLorca, J., González, C., Molina-Aldareguía, J. M., Segurado, J., Seltzer, R., Sket, F., Rodríguez, M., Sádaba, S., Muñoz, R., & Canal, L. P. (2011). Multiscale modeling of composite materials: a roadmap towards virtual testing. *Advanced Materials*, *23*(44), 5130–5147.

Llorca, J., Needleman, A., & Suresh, S. (1991). An analysis of the effects of matrix void growth on deformation and ductility in metal-ceramic composites. *Acta Metallurgica et Materialia*, *39*(10), 2317–2335.

Mannering, F. L., & Washburn, S. S. (2020). *Principles of highway engineering and traffic analysis*. John Wiley & Sons.

Miao, W. F., & Laughlin, D. E. (2000). Effects of Cu content and preaging on precipitation characteristics in aluminum alloy 6022. *Metallurgical and Materials Transactions A*, *31*, 361–371.

Muratoglu, O. K., Bragdon, C. R., O'Connor, D. O., Jasty, M., & Harris, W. H. (2001). A novel method of cross-linking ultra-high-molecular-weight polyethylene to improve wear, reduce oxidation, and retain mechanical properties: recipient of the 1999 HAP Paul Award. *The Journal of Arthroplasty*, *16*(2), 149–160.

Niemz, T. (2014). *Reducing braking distance by control of semi-active suspension*. diplom. de.

Rajak, D. K., Pagar, D. D., Kumar, R., & Pruncu, C. I. (2019). Recent progress of reinforcement materials: A comprehensive overview of composite materials. *Journal of Materials Research and Technology*, *8*(6), 6354–6374.

Santoso, S. (2013). Studi Pemanfaatan Campuran Serbuk Tempurung Kelapa-Aluminium Sebagai Material Alternatif Kampas Rem Sepeda Motor Non-Asbestos. *Jurnal Nosel*, *2*(1).

Sathyamoorthy, G., Vijay, R., & Singaravelu, D. L. (2022). Synergistic performance of expanded graphite—mica amalgamation based non-asbestos copper-free brake friction composites. *Surface Topography: Metrology and Properties*, *10*(1), 15019.

Sienkiewicz, A., & Czub, P. (2017). Novel bio-based epoxy-polyurethane materials from modified vegetable oils-synthesis and characterization. *Express Polymer Letters*, *11*(4).

Siqueira, G., Bras, J., & Dufresne, A. (2010). New process of chemical grafting of cellulose nanoparticles with a long chain isocyanate. *Langmuir*, *26*(1), 402–411.

Sultan, S., Purnamawati, P., & Mandra, M. A. S. (2022). Pengembangan Model Problem Based Learning Berbasis Multimedia Interaktif Mata Pelajaran Sistem Rem Teknik Kendaraan Ringan di SMK. *Jurnal Impresi Indonesia*, *1*(4), 376–386.

Wang, X., Gao, X., Zhang, Z., Cheng, L., Ma, H., & Yang, W. (2021). Advances in modifications and high-temperature applications of silicon carbide ceramic matrix composites in aerospace: a focused review. *Journal of the European Ceramic Society*, *41*(9), 4671–4688.

Wu, S., & Cheng, H. S. (1991). *A sliding wear model for partial-EHL contacts*.

Xiao, Y., Zhang, Z., Yao, P., Fan, K., Zhou, H., Gong, T., Zhao, L., & Deng, M. (2018). Mechanical and tribological behaviors of copper metal matrix composites for brake pads used in high-speed trains. *Tribology International*, *119*, 585–592.

Yashwhanth, S., Mohan, M. M., Anandhan, R., & Selvaraj, S. K. (2021). Present knowledge and perspective on the role of natural fibers in the brake pad material. *Materials Today: Proceedings*, *46*, 7329–7337.